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## **Enabling Workers to Enter Industry 4.0: A Layered Mobile Learning Architecture**

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**Abstract:** Manufacturing companies have to meet a lot of challenges in continuing training for employees. Especially on the way towards industry 4.0 the workforce needs to be able to handle fast changing environments and ever-changing working contexts. Furthermore, they have to be familiar with constantly new technologies (e.g. complex user interfaces, mobile devices) that are introduced during the process of company development. Due to this, working people are facing a lifelong learning process and need to evolve to knowledge workers. To fulfill these requirements new concepts are necessary for human resources development directly at the workplace and therefore adequate artifact designs. In this paper we design a layered architecture for mobile learning at the workplace. This layered approach offers the possibility to educate employees with different qualifications and skills using an integrated solution. Further, we propose to implement appropriate components at each layer to support different kinds of learning.

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## Enabling Workers to Enter Industry 4.0: A Layered Mobile Learning Architecture

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### Abstract

*Manufacturing companies have to meet a lot of challenges in continuing training for employees. Especially on the way towards industry 4.0 the workforce needs to be able to handle fast changing environments and ever-changing working contexts. Furthermore, they have to be familiar with constantly new technologies (e.g. complex user interfaces, mobile devices) that are introduced during the process of company development. Due to this, working people are facing a life-long learning process and need to evolve to knowledge workers. To fulfill these requirements new concepts are necessary for human resources development directly at the workplace and therefore adequate artifact designs. In this paper we design a layered architecture for mobile learning at the workplace. This layered approach offers the possibility to educate employees with different qualifications and skills using an integrated solution. Further, we propose to implement appropriate components at each layer to support different kinds of learning.*

### 1. Introduction

In the context of industry 4.0, companies increasingly need the ability introduce new technologies and production processes, and upskill employees, quickly and efficiently. There is growing interest in cyber-physical systems (CPS), that can address such imperatives and solve problems autonomously, but their use is still not widespread [24]. The rapid introduction of new technologies and frequently changing areas of responsibility can pose employees with several challenges. Employees have to improve their problem-solving skills continuously whilst trying to achieve the highest efficiency standards. They have to acquire situation-dependent specialist knowledge for ever-changing working contexts to meet the challenges on the way to become

knowledge workers. Similar concepts to industry 4.0 are also discussed as “smart manufacturing” [7] or “advanced manufacturing” [14].

Nelles et al. [24] propose a new role of the human in industry 4.0 companies. Rather than being involved in routine work activities, the human should be put in a position where s/he can quickly make the right decisions in production planning and control. Therefore they need the help of decision support assistance systems that fulfill an ergonomic and human-centered design [24].

In this study, we strengthen and extend this rationale with the use of mobile learning at the workplace. Mobile learning has been described as a suitable concept for individual and context-related knowledge transfer and is widely recognized in the literature [12] [34] [20]. The benefits of mobile learning for on-the-job training are the support of communication and knowledge exchange, on-demand access to experts, and learners that participate more actively in the learning process by engaging in authentic real-life situations [20]. For that reason, we propose an integrated system that supports employees with mobile learning technologies (mobile devices and suitable designed artifacts), so that in-situ mobile learning can be realized directly at the workplace.

We further propose to address workers with different levels of qualification with a single solution, so that less qualified people can benefit from specialized knowledge of highly skilled colleagues. Our study aims to support the process of acquiring and exchanging knowledge among employees by providing appropriate software artifacts to enable time and place independent learning (‘just-in-time’). As we have to address a range of functional and non-functional requirements of differing complexity, we integrate components supporting specific learning opportunities and arrange them in layered mobile learning architecture. On each layer these components are deployed for various teaching techniques to support problem situation management, to increase decision support skills and facilitate a work-related lifelong

learning. This enables the workforce to face the challenges that emerge through developments towards industry 4.0. The research accordingly addresses the following research question: how can employees be enabled with mobile technologies directly at the workplace to evolve to knowledge workers?

To answer the question we first analyze existing concepts and proven approaches to employee development in the literature to and propose remaining issues or gaps. We then identify specific employee development problems at an industrial partner in a case study. Finally, we design a layered architecture for mobile learning at the workplace.

## 2. Related work

Industry 4.0 represents a revolution in work processes, including the education of workers [17]. Production is increasingly driven by globalization, product individualization, shorter product life cycles and volatile markets. Key challenges in this context are shorter engineering phases and quicker ramp-up of production lines [31]. Cyber-physical systems can help cope with these challenges, with the aim that context-aware automation will adapt production and logistics processes to new configuration requirements automatically [31]. Modern companies utilizing such CPSs have established daily work processes, which increasingly integrate information creation and consumption. They are based on workers who engage in knowledge-intensive tasks (e.g. decision-making, knowledge-production), that resist standardization because of their unpredictable character [29]. This will be intensified by the development to industry 4.0, because jobs and competence profiles are radically transforming. To enable lifelong learning and workplace-based continuing professional development, appropriate training strategies have to be implemented. On this basis, the question arises, how such a transformation of the workforce towards knowledge workers can be realized.

The widespread availability of mobile devices, offers the opportunity to bring mobile learning directly to the workplace. This allows flexible, time and device independent, on-demand access to educational resources, experts, peers and services from any place [2]. Additionally, it should enable enhanced worker autonomy and flexibility [32]. With a mobile learning approach, workers can be empowered to acquire the knowledge they need when they need it. This includes knowledge for complex processes or systems (such as in complex manufacturing), in which it may not be feasible to understand all components or to perform all services from memory [17]. As it is not adequate to

gain the required knowledge ‘just-in-case’, the use of mobile devices and specially designed mobile learning artifacts is needed for learning anywhere at any time. In addition, different kinds of learning should be supported using blended learning concepts. Jennings [18] sums this up: “In fact, all workforce development can be distilled down to four basic elements: experience, practice, conversations and reflection”.

According to this and respecting the analytical framework of Figueiró et al. [10] appropriate teaching techniques for a higher education (among others) are action/experiential learning and problem-based learning. Action and experiential learning means learning by doing or learning from experience and is one of the most effective ways to engage participants by actively involving them in the problematization process. The inherent research and problem solving promotes their critical reflection [10]. The problem-based learning technique assumes that learning is initiated by an authentic, ill-structured problem [16]. Learners develop problem-solving and self-directed learning skills while working toward a solution. This leads to newly constructed content knowledge. In addition, learners need knowledge in non-predictable situations and for even more unpredictable user requirements. Therefore learning systems are designed to satisfy these user requirements by delivering appropriate learning content and services, and by being aware of situation changes through automatic adaption [5]. This allows a situation-based learning.

It seems that the training techniques mentioned above have the potential to support context-aware mobile learning that should be best supported with mobile technologies and suitable designed artifacts. Through new capabilities of the mobile devices, the working context can be determined as well as the machine states observed. This enables a context-aware learning and personalizes the learning experience [2].

But how can context-aware learning be supported? On a most fundamental technical level, we need to develop an architecture to enable new contextual learning. In the subsequent paragraphs we review previous publications on mobile learning architectures. These publications describe a) a generic technical architecture for implementing mobile learning or b) the architecture of a specific mobile learning implementation. Baccari et al. [2] give an up-to-date overview of different projects dealing with mobile learning architectures.

Parsons and Ryu [25] provide four software architectures for mobile learning: non adaptive mark-up, adaptive mark-up, mobile client side application and smart client with server connectivity. These describe the technical infrastructure for mobile applications (markup technology, server connection).

Wang et al. [36] describe a mobile-optimized application architecture that consists of different layers and proposes to integrate a remote laboratory into a mobile environment. The layers describe the technical components and how they are used to form a solution for realizing the requested purpose.

Zhao and Okamoto [39] propose a device-independent architecture for mobile learning. Content is provided based on the characteristics of mobile devices and mobile learners. They focus on how content on a mobile device can be adapted to user characteristics based on social network profiles. This architecture again describes the architecture of one specific solution.

Fioravanti et al. [11] developed ICMC MLE, a mobile learning environment. The architecture is based on Ref-mLearning that is adapted from EDUCAR (a reference architecture for learning environments) and focuses on mobile learning contexts. This architecture provides guidance how new mobile learning environments can be developed. However, it is not intended for integrating existing components.

These studies investigate the use of mobile learning in different fields (museum, laboratory etc.), with a focus on the technical implementation of the architectural components, but do not contribute to the support of different training techniques for a coherent set of scenarios. Thus there is still a need for an overall architecture for industry 4.0 mobile learning.

Beside the architecture considerations there were some projects that already handle the combination of artifacts that support different intended activities associated with learning at the workplace. They also provide their own architectural approach. The PRiME<sup>1</sup> project provides a seamless learning framework for the connection of learning and work processes [13]. The project aims to support inspectors with their daily tasks of inspecting trains and supports continuous creation of knowledge and reflection at three different layers. The first layer (personal learning environment) represents the knowledge home for the learners and enables them to create an individual learning environment by assembling knowledge assets (bundles, snippets and private annotations), consisting of text, image, audio and video. The second layer (personal knowledge network), supports interaction with selected peers to share, comment and rate the materials for a collaborative knowledge creation. The third layer (network of practice) shares materials that are used within the company. On each layer different mobile applications are implemented to support the activities.

The AmbiWise<sup>2</sup> project provides a collaborative system with adaptive and multimodal user interfaces for a mobile and context-aware interaction and easy access to knowledge in companies [28]. The project uses a knowledge repository that integrates existing sources and provides a system architecture that contains different micro services, where each service models a functional aspect. This enables it to be operated in a distributed way over various locations. The architecture consists of three different layers: the underlying layer of basic services representing the backend functionality and the enterprise content management system, the orchestration layer for the integration services, and the UI layer that is implemented as a web application. Except for the knowledge repository all services and components were self-implemented throughout the project.

These projects are intended to support the implementation of especially designed artifacts and services to build learning environments for different purposes. To date, the integration of existing components to support different kinds of learning has been insufficient. This is the focus of our research.

### 3. Method and data collection

Our research question is based on the design science paradigm that seeks to increase human and organizational capabilities by creating new IT artifacts and recommendations [15]. According to the design science research methodology (DSRM) [26] we structured our research into the six phases: (1) problem identification, (2) objectives definition, (3) design and development, (4) demonstration, (5) evaluation and (6) communication. For evaluation we use the evaluation framework developed by Sonnenberg and vom Brocke [33], which provides specific evaluation steps after each activity of the DSRM framework. For our analysis we adopt an ex ante evaluation of identified problems and the designed artifacts. Further, we use the design-theorizing framework [22] to derive the abstract problem in the problem identification phase from literature. The abstract problem is defined using the Explanatory Design Theory approach [4] that describes requirements as conditions of the problem situation and necessary capabilities of the actors. Based on the findings during our investigations in a manufacturing company, an internationally operating automotive supplier, we instantiate the abstract problem to clearly define instance problems. Further, we develop the instance solutions from the results of

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<sup>1</sup> Professional Reflective Mobile Personal Learning Environments;  
<http://prime.rwth-aachen.de>

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<sup>2</sup> <http://www.ambiwise.de/>

our case study in the design phase and propose an abstract solution that constitutes our contribution.

Following the DSRM, we analyzed the information collected from our industrial partner and extracted the requirements from semi-structured interviews that we carried out over one and a half years, with a range of people with various levels of work experience. We created personas [3] and problem scenarios in the analysis phase. In a claim analysis, we identified positive and negative characteristics of the investigated situations whereby the negative findings potentially are able to form the requirements of the solution. We then developed interaction design scenarios iteratively in the design phase using the scenario based design framework by Rosson and Carroll [30]. These scenarios use mock-ups [9] that describe the interactions of a protagonist with a specially designed software solution. Personas and scenarios were evaluated in on-site workshops and interviews. In the implementation phase we implemented prototypes that were demonstrated and evaluated at the company, whereby one prototype was evaluated in a field use. The main result of our case study was a set of artifacts, supporting different kinds of mobile learning that we implemented in prototypes of various maturity levels within a layered mobile learning architecture. Thus, the mobile learning architecture captures core top-level design knowledge needed to implement mobile learning in an industry 4.0 setting. Finally, we communicate our results with this publication.

#### 4. Abstract and specific problem

Based on prior work from the literature we formulate the requirements of the intended solution as generic capabilities of a possible solution and define existing conditions using the Explanatory Design Theory approach [4]. Conditions (physical circumstances that influence how something happens [4]) and capabilities (abilities required to do something [4]) were identified during our case study.

First we explain three general conditions that form the initial situation at the workplace. The first condition is the *restricted human capacity for knowledge absorption* (CON1) [8]. Expert knowledge is necessary for daily tasks that should be transferred directly if needed. A second important condition is the *temporary nature of learned knowledge* (CON2) [8]: knowledge, that is not used actively will be forgotten [23]. Thirdly, *learners have varied prior knowledge*, so that they have different capabilities to gain new knowledge (CON3). To evolve the workforce to knowledge workers the knowledge transfer has to be 'just-in-time' [27]: only that knowledge should be

transferred in an adequate way, which is necessary for the current working situation. To define the requirements in more detail we formulate the following functional capabilities of the solution:

*The future learner can obtain knowledge individual, modularized and time-independent* (CAP1) [8]. The intended solution is embedded in the daily working routines of workers. The most promising approach is to use unplanned small time frames for mobile learning (e.g. because of a delay of material delivery). Therefore, the solution has to be available on mobile devices for a time- and place-independent access and provides personalized knowledge in small snippets to foster short learning episodes.

*The future learner can transfer his/her personal knowledge and experience to other learners and can obtain such knowledge from others* (CAP2) [8]. The transfer of "sticky" knowledge is important in problem situations and during decision-making processes directly at the workplace. Hence, the future system has to provide support for collaborative processes and ad hoc communication.

*The future learner can obtain knowledge appropriate to his/her prior knowledge* (CAP3). Since the prior knowledge and skills of the workers vary considerably the designed solution should be able to provide learning content in several degrees of difficulty.

*The future learner can gain practical experience directly within his/her working-context without influencing the current production processes* (CAP4). Learners that use the envisaged system have to make changes in their current working context to acquire knowledge through learning by doing. These changes must not influence the production flow. For this purpose the solution has to provide capabilities for experiments and simulation of learning situations.

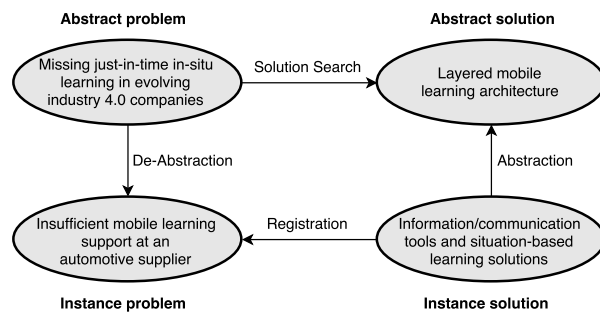
*The future learner combines real problem solving situations with context-aware knowledge content and incorporate experts if required* (CAP5) [8]. The learning activities and the daily working procedures should be seamlessly brought together. The planned solution allows mobile problem solving support, providing problem descriptions and solution capabilities, with integrated remote support by experts.

*The future supervisors are able to ensure the quality of the knowledge content* (CAP6). The solution should provide mechanisms for the review and management of content as well as the support for supervisor-exclusive content provisioning procedures.

Beside this there are non-functional capabilities that influence our further considerations. These are the maintainability, scalability, modularization and expandability of the envisaged software solution.

At our industrial partner we investigate the current situation in workforce development and identify the

problems that prevent the development of capabilities. Figure 1 presents the results of the theorizing of employee development and gives an outlook to the designed solution.



**Figure 1. Theorizing employee development**

We can summarize the abstract problem as insufficient ‘just-in-time’ in-situ learning in companies, which evolve towards industry 4.0. Our partner company uses the traditional German mentoring approach whenever a worker has to acquire a new skill i.e. skilled workers show the unskilled workers how to e.g. operate a machine and accompany them until they are ready to work independently. Some basic knowledge can furthermore be acquired autonomously using stationary self-learning platforms. As described earlier this is appropriate for an environment with moderate change rates. However, it is not appropriate for the increasing pace as companies move towards industry 4.0.

## 5. A layered mobile learning architecture

We propose to embed learning directly in the work processes using mobile technologies. To accomplish this we propose an architecture for mobile learning that implements learning components in three layers.

*Data and information layer:* The lowest layer represents the data and information repositories for the other layers above. It is the machine data collection, aggregation and archiving, as well as the knowledge content provision layer that delivers the content for the upper learning tools and artifacts. These tools and artifacts use dedicated data schemas and models to manage their required data structures. The access can be realized decentralized whereby the components of the higher levels can be operated in a distributed way. Beside this the linkage between the knowledge content and the context provided by machine data and configurations is realized in this layer.

*General, situation-independent learning layer:* The second layer consists of information and communication tools for the learning of facts, the

provision of tutorials and training videos, and cooperation between employees. These tools are already widely used in practice and will be integrated within this layer. The repositories described earlier manage the knowledge produced and required by these tools. The components of the upper layer integrate them by linking to the respective content or by directly integrating their functionality. Additionally, we implement a component for experimental contexts of machines in this layer. This component provides specific playgrounds that enable employees to learn by experience. It receives data in a well-prepared and structured form from the machine data repository. Therefore, appropriate algorithms are necessary to process the raw data accordingly as well as the possibility of managing the experimental ranges.

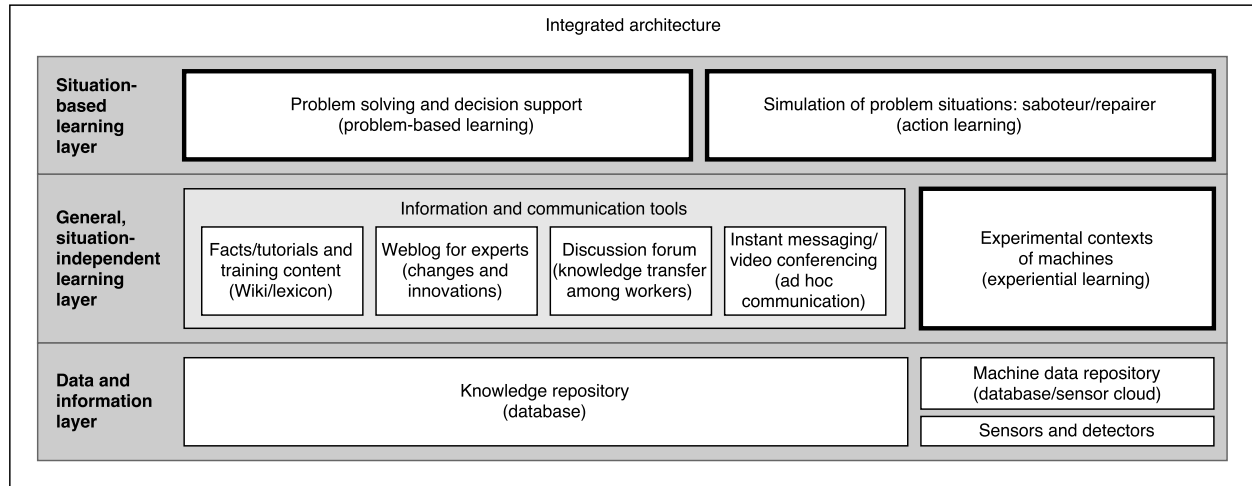
*Situation-based learning layer:* The upper layer supports components for situation-based learning. These can be used for problem-based learning, whereby employees can obtain situation-aware knowledge and receive support in problem-solving tasks directly at the workplace by the use of integrated tools from the second layer, and action learning through simulations of problem situations that are customized for the respective working context and the level of qualification of the worker. For the collaborative activities the components of the layer underneath are well integrated into these artifacts to ensure the pursued knowledge transfer while dealing with problem solving and decision support situations.

The architecture represents the overarching design concept and supports a blended learning approach. Figure 2 depicts the layers with their corresponding components. The complexity of the learning support realized by the components implemented at each layer increases from bottom to top as well as the required qualification of the learner.

### 5.1. Data and information layer

As the base of the architecture, the data and information layer provides the necessary data and information for all layers above. We recommend two kinds of repositories in this layer: a repository for the company’s knowledge content and a repository for machine data. The layer fulfills the non-functional requirements scalability and expandability.

The knowledge repository contains all the content provided by training supervisors and experts for base-level and advanced education and training, and content created by users when interacting with the components of the layers above. It manages all the produced un-, semi- and structured content of the upper layer components. Table 1 shows the different types according to their purpose.



**Figure 2. Layered mobile learning architecture**

**Table 1. Types of knowledge content**

Purpose	Content type
Communication support	<ul style="list-style-type: none"> <li>Instant messaging (text) (Video conferences are streamed.)</li> </ul>
Basic education and training	<ul style="list-style-type: none"> <li>Facts (topic-based articles; text)</li> <li>Tutorials (text/images)</li> <li>Training videos (video data)</li> </ul>
Advanced education	<ul style="list-style-type: none"> <li>Articles in weblogs (text/images/video data)</li> <li>Posts in discussion forums (text/images)</li> <li>Problem solutions (text/images/audio-/video data)</li> <li>Simulated problem scenarios (text/images/video data)</li> </ul>

According to the content type there are different kinds of data. Audio and video data represent unstructured data. The natural text inserted by the content providers (e.g. comments, blog entries, problem solutions) is semi-structured data as the comments and entries itself are structured but the text within is unstructured [1]. Facts and tutorials are well-structured data because the structure is predefined. Due to the heterogeneous nature of the data it is important to use appropriate mining, search and filter mechanisms to find and provide the data to the recipients in an appropriate manner. Similarly, an extensive knowledge repository was also proposed by the AmbiWise project to gather expert knowledge of complex maintenance tasks [28].

The second repository manages the machine data. It contains all the data from sensors and detectors of the machines that are connected to the internal network. We recommend a separate repository for the following reasons: As the raw machine data cannot be processed

directly by humans it must first of all be prepared. For that reason, specific mechanisms have to be part of the repository for the aggregation and analysis of the data. Further, the raw data has to be collected and archived for quality assurance purposes and revisions and will therefore be used by other systems as well.

For mobile learning applications the machine data should be available in real time and will be prepared and aggregated when received. This allows real time feedback through human-centric pervasive applications [38] and a linkage of the data within specific time frames to problem situations, simulations, process changes or test series. This relation to the context is also applied within the PRiME project for the Personal Learning Environment, where annotations and snippets are context-related to reduce the amount of knowledge presented by the mobile device [13].

## 5.2. General, situation-independent learning layer

This second layer implements components for time and situation independent mobile learning. The layer supports ad hoc learning in a company through time- and place-independent knowledge provision and exchange, and fulfills the non-functional requirements maintainability and modularization. We use established information and communication tools for learning [37] to support the members of the workforce. Information and Communication tools are crucial in the workplace because they support organizational socialization [21]: Interaction and feedback are critical elements of all information and communication processes [19]. As Wagner and Bolloju [35] stated, different types of collaboration are best supported by different social

media technologies. These technologies are Wikis, Weblogs and Discussion Forums.

Wikis are able to build relationships to other content in the repository (knowledge organization) and offer ease and efficiency in representation and sharing of knowledge. Wikis support the collaboration of employees in different time and place environments, are used to support employees with all levels of experience and can effectively be an open source technology for knowledge content. That makes them very suitable for mobile learning environments. In addition, they provide a powerful search function to find the required knowledge content. A Wiki in the context of our integrated solution will be used to provide the factual knowledge, tutorials and training videos. The content can be used in all other components of this layer and the layer above and could easily be linked in postings, blog entries, problem description and solutions, simulation and experiment descriptions. This allows effective access to the required learning content.

Weblogs (Blogs) are personal web pages that are organized in a reverse chronological diary form. A Weblog is managed by an individual author or a group of collaborating authors [35]. Because they represent anytime and anyplace information and knowledge site they are also very suitable to support mobile learning. In the context of learning communities in manufacturing companies they provide an ideal medium for experts to broadcast their expertise to a large follower community [35]. So the newest technologies or processes can be announced and explained in a blog entry to inform all interested employees. To inform only a specific group of addressees, micro blogging within the company internal network is also suitable. Finally blog entries can also be linked to build more comprehensive knowledge content. A lot of companies are already using blogs to update their employees on developments that are considered to be important [19].

Discussion forums are one of the oldest knowledge sharing technologies [35]. Messages created by users are broadcast to all list members. Readers have the possibility to rate the quality of the postings and to configure the types and topics of the desired information. They are adequate tools in the context of mobile learning, especially for the discussion of less time-critical problems. A problem can be posted and discussed with others. Correct answers and hints can be marked as solution and can be rated to improve quality. Thereby employees can benefit from the experience of other colleagues.

Further instant Messaging and video conferencing tools should be available at this layer. These ad hoc

communication components can be used at any time and anyplace to contact other employees or experts.

The information and communication tools address CAP1 while facilitating time- and place independent acquisition of knowledge. The required content is prepared, modularized in appropriate snippets to ensure short learning episodes (Wiki, Discussion Forum, Blog). The PRiME project in contrast uses knowledge assets like snippets, bundles and private annotations for assembling personal learning environments that can be searched directly at the workplace using mobile devices. The content is exclusively created by specialist authors and can be enriched by annotations of the workforce using especially implemented applications [13]. Beside this CAP2 is addressed, because the tools allow a transfer of expert knowledge between the members of the workforce (Discussion Forum, Blog). Similarly the AmbiWise system is used to document maintenance processes to gather experts' knowledge of complex maintenance tasks within a knowledge repository [28]. Fulfilling CAP3 an employee can gain new knowledge from the Wiki according to his/her prior knowledge. The components address CAP5 as they enable ad hoc communication with other colleagues, especially experts. Furthermore, the tools support CAP6 by providing an administrative/editorial backend for supervisors (experts). Only authorized people are able to execute the management of Wiki and blog entries. Discussion forums have functions implemented that allow review and publication processes. All of this ensures a high quality of the created content. The quality of the created knowledge content within the PRiME project ensures qualitative content by specialist authors. Only approved and highly rated annotations will be adopted to the knowledge base [13].

The technologies mentioned above will also help the building and sustaining of learning communities and to expand learning possibilities to be available anytime and anyplace.

In the second layer another component implements experimental contexts for learning at the machines. These playgrounds fulfill CAP4. They form the basis for experiential learning and define 'safe' ranges of reference values employees can change settings within. As we found out during our research, less qualified workers do not feel able to make changes during ongoing production because they fear negative consequences (broken machines, destroyed pieces of material etc.). Within the predefined value ranges they cannot affect the current production process and are able to change settings without significantly interfering with the quality of output. So they can learn how different settings can improve or deteriorate the quality with direct feedback from the machine.



### 5.3. Situation-based learning layer

The situation-based learning layer is based on the second layer. The components of the general learning layer are seamlessly integrated into the artifacts of this layer to be available in more complex scenarios that are addressed here. We propose two components to meet the specific challenges that arise in companies evolving to industry 4.0: 1. assistance for situation-related problem solving and decision support and 2. simulation of problem situations. Assistance for problem solving enables workers to embed learning while solving real problems that are complex or have to be solved urgently due to the time critical aspect. Assistance is specific to the few people that are currently involved in the problem situation.

The component for problem solving and decision support (PSDS) enables workers to solve more complex problems by themselves. They can search in the related repository of prior problems whether they can find a solution to their problem. If not, the worker describes the problem and steps that were already done to make it easier for a supporter to visualize the problem. This encourages the person to reflect deeply on the problem's characteristics, which results in an improvement of the problem-solving abilities. After that problem descriptions can be reviewed and commented on by experts. According to the priority of the problem an expert sifts the problem description and answers with a possible solution. This results in the documentation of specialized knowledge and makes it available to other people. The originator tries to solve the problem using the provided solution. Additionally, s/he can use the communication tools for an ad hoc contact to experts or the Wiki for finding appropriate fact knowledge that can help with solving the problem. Campatelli et al. [6] designed a similar artifact for managing defects and solutions, however, without providing support for the documentation of prior steps.

The PSDS component addresses CAP4, whereby the worker combines real problem solving situations with context-aware knowledge content to achieve better problem solving skills. If required it is possible to get support by experts (using the component itself or ad hoc communication tools). With this approach the problem solving process will be well documented and helps others to treat similar problems.

The second component offers simulating problem situations directly at the machine to realize action learning. An expert creates a problematic situation for a specific machine and the learners explore the functionality of the machine by trying to solve the problem. Such a simulation can be designed for people of different education levels. Employees can reach a

new level of qualification by solving different simulations.

The component for the simulation of problems addresses CAP3 by simulating real world problems within an experimental context. It also addresses CAP2 because an expert uses his/her specialist knowledge to create such simulations. This knowledge is suitable to be transferred to the worker that performs the simulation. The projects AmbiWise and PRiME do not directly address a situation-based learning by forcing an application-supported reflection of situational awareness of the performed activities.

## 6. Discussion

The exchange of knowledge between the members of the workforce is critical for the success of manufacturing companies. Therefore, enabling the workforce with heterogeneous qualification skills to evolve to knowledge workers is necessary [29]. Employees have to be engaged to learn more actively in authentic real-life situations [20]. This can be achieved by using mobile technology directly at the workplace to allow a 'just-in-time' access to educational resources from any place [2]. Because of the complexity of the daily working tasks, a 'just-in-case' learning approach is not adequate anymore [17]. So learning in the era of industry 4.0 should be supported using blended learning concepts [18] to learn situation-independent as well as situation-dependent knowledge. Therefore, it is proposed to use appropriate teaching techniques like action/experiential learning and problem-based learning [10]. In addition, the new capabilities of mobile devices offer the determination of the working context as well as the observation of machine states for a context-aware learning and personalizing of the learning experience [2]. To provide mobile learning environments different architectural approaches are discussed in prior publications [2] [25] [36] [39] [11]. As these studies focus on the technical implementation of the architectural components and do not support different training techniques for a collaborative, situation-independent as well as a situation-based learning, there is still a need for an architecture supporting these techniques.

In this paper we developed a layered architecture for supporting employees directly at the workplace with mobile learning components for different learning activities, respecting the results of already finished projects [13] [28]. The architecture consists of three different layers that are built upon one another.

The data and information base provides the data for all layers above. It is necessary to provide the required

knowledge content and context information in form of machine data within special designed repositories. The AmbiWise and PRiME projects propose a knowledge repository as well, to manage the company content as multimedia content but do not use a separate repository for machine data. For communication among the workforce, the general learning layer implements tools that are accepted in literature to support learning at the workplace. The positive influence of these components to the relationship of the participants at the shop floor is well known and can be strengthened with our research results. These components are also well accepted by most people so that they can be used without difficulties. The experimental contexts of production systems enable the workers to change settings directly at the machines without the risk of production disruptions and without the supervision of experts. This layer supports people with low, medium, and high level of qualification. The latter group mainly acts as the producer of the learning content and the supplier of expert knowledge. Such a possibility for performing experiments for an experiential learning is not supported by the AmbiWise and PRiME project.

The third layer delivers special customized solutions to develop problem solving and decision support skills. This layer is arranged for people with a medium or high level of qualification because a certain degree of base knowledge is necessary for a further education.

Our study focuses on the arrangement of the different components and technologies within the layered architecture. We state that our contribution is an architectural approach of the implementation of components for different kinds of learning and different levels of qualification within one integrated and modularized solution. In summary, the entirety of the components builds up an integrated solution that supports employees at each level of qualification during their daily working tasks and which is available anytime and anyplace due to the orientation of mobile learning.

## 7. Conclusions and future work

The architecture developed in this paper is designed to support employees to develop their skills during situation-based learning activities directly at the workplace. It addresses the challenges of workforce development in manufacturing companies and can be implemented in these companies for preparing the workforce for the entry to industry 4.0. To prove the further applicability an investigation in other companies is necessary and should be carried out by further research.

The implementation of an instance of our architecture is still in progress. We are currently implementing and evaluating the experimental contexts and the two components of the situation-based learning layer: one for problem solving and decision support, and one for the simulation of problem situations.

Further topics we have to discuss are data protection and security, as well as the access possibilities from outside of the company network.

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